A SHORT-TERM ECOLOGICAL STUDY OF BLAKETOWN LAGOON, GREYMOUTH, NEW ZEALAND

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ABSTRACT

A short-term hydrological and biological investigation of Blaketown Lagoon, Greymouth, New Zealand (171°12'E, 42°27'S), was carried out in October-November 1973 and February 1974. The history of modifications to the lagoon is discussed, and a brief description is given of the lagoon and the surrounding vegetation. The effects of the construction (during 1967) of a weir at the outflow from the lagoon are: alterations in inflow and outflow patterns, a raising of the water level by 0.67 m, and a marked lowering of the salinity. Nutrient levels within the lagoon are high, and sediment analyses showed silt-clay fractions of over 90%, and large quantities of organic matter.

Bottom fauna was sampled at four stations. The dominant organisms were species characteristic of estuarine areas with very low salinities: the polychaete *Scolecolepides benhami*, oligochaetes, gastropods of the genus *Potamopyrgus*, and chironomid larvae. The effects of the alteration to the outlet, and construction of the weir are discussed in terms of increased nutrient input, the nature of the sediments, and the flora and fauna.

INTRODUCTION

This investigation was carried out at the request of the Blaketown Lagoon Committee, which had been established by the Greymouth Borough Council to consider the future management of Blaketown Lagoon, Greymouth. The problems associated with this body of water and surrounding wetlands largely arose after the construction of a new outlet to the lagoon and the sealing off of the old outlet in 1967-68 (Fig. 1).

Since then there has been a considerable increase in the plant growth in the lagoon, with the result that in the summer large accumulations of rotting plant material on the tidal mud-flats, especially at the upper end, have become objectionable to local residents. Over the years, the results of infilling and the accumulation of rubbish have made parts of the lagoon unsightly. Also, various proposals have been made for the future of the area, ranging from almost complete reclamation (as shown on the Provisional Town Plan for the Greymouth Borough) to the development of the area for a marina.

The present study was directed towards an understanding of the causes of the recent changes in the lagoon and in particular, the marked increase in algal growth. This involved the

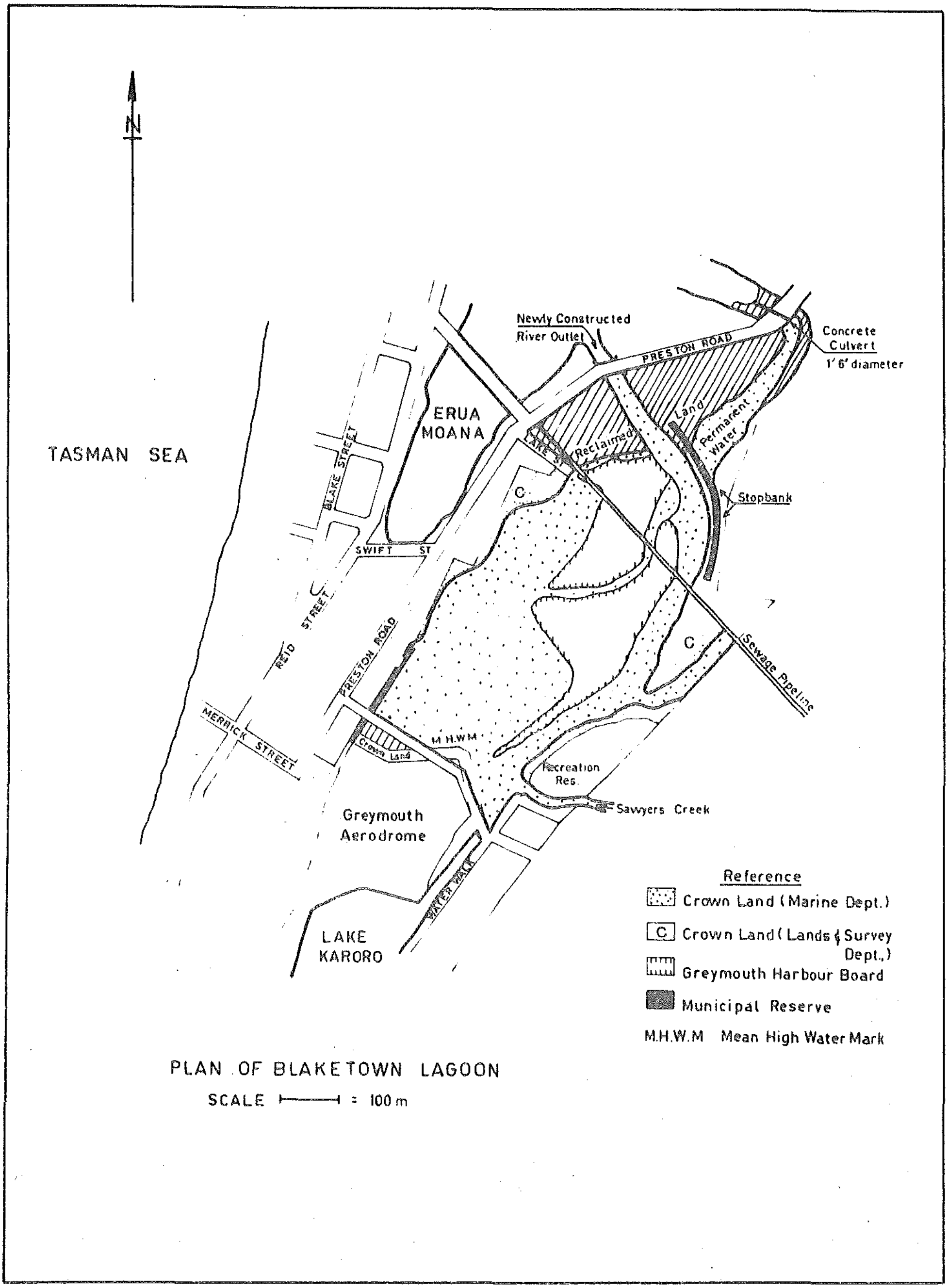

Fig. 1. Map showing the location and present boundaries of Blaketown Lagoon.

investigation of the hydrology, nutrients, sediments, bottom fauna and vegetation documented here.

After a preliminary investigation, two visits of several days' duration were made to the area, one in October-November, 1973, and another in February, 1974. On both occasions water samples, sediments and representative collections of plants and animals were taken for subsequent analysis.

HISTORY

Blaketown Lagoon is a remnant of a series of interconnected lagoons that developed behind the shingle beaches and sand-dunes on either side of the Grey River. It was formerly more extensive than at present, with a broad opening into Erua Moana, a second lagoon that opens into the Grey River. Previously, both of these lagoons would have been true estuarine areas with fluctuating salinities ranging from freshwater to almost fully saline water depending on tidal level and distance from the sea.

Over the years, the area of Blaketown Lagoon has been progressively reduced by reclamations and roading. At the upper end, much of the reclamation was associated with the development of the Greymouth Aerodrome. This caused the formation of Lake Kororo. In 1945 (Fig. 2) Lake Kororo was open to the main lagoon, and at that time it was probably saline. Now it is effectively sealed off and salinity determinations made in February 1974 showed that it was freshwater.

In 1967 it was decided to close off the old entrance into Erua Moana and to construct the present outlet to give a more direct outlet and to provide further land for reclamation. This present outlet is narrower than the old one, especially where it is confined at the Preston Road Bridge (Fig. 2). It was the scouring of the bridge approaches that led to the installation of the rock weir immediately upstream from the bridge.

PHYSICAL DESCRIPTION

The lagoon (Fig. 1) is about 600 m long, and is roughly rectangular in shape. Sawyers Creek enters the south-east corner after running through urban Greymouth. A second smaller creek, known locally as Tarry Creek, enters about midway along the eastern boundary. Tarry Creek flows through the Greymouth industrial area and receives effluents from the railway sheds, a gas works and a brewery. Sawyers Creek receives water from storm-water drains and, on occasions, effluent overflows from the Greymouth Borough sewage system which discharges untreated sewage into the Grey River. The main drainage channel runs along the eastern boundary before it opens into Erua Moana.

Along the southern, eastern, and northern two-thirds of the western boundaries are narrow strips of Crown Land reserves. The remainder of the western boundary is completed by a Municipal Reserve. About 40% of the area of the lagoon has been vested in the Greymouth Harbour Board (Gazette, 1908). From old photographs it is apparent that this area largely coincides with high banks which were covered at that time (c. 1908) with rooted

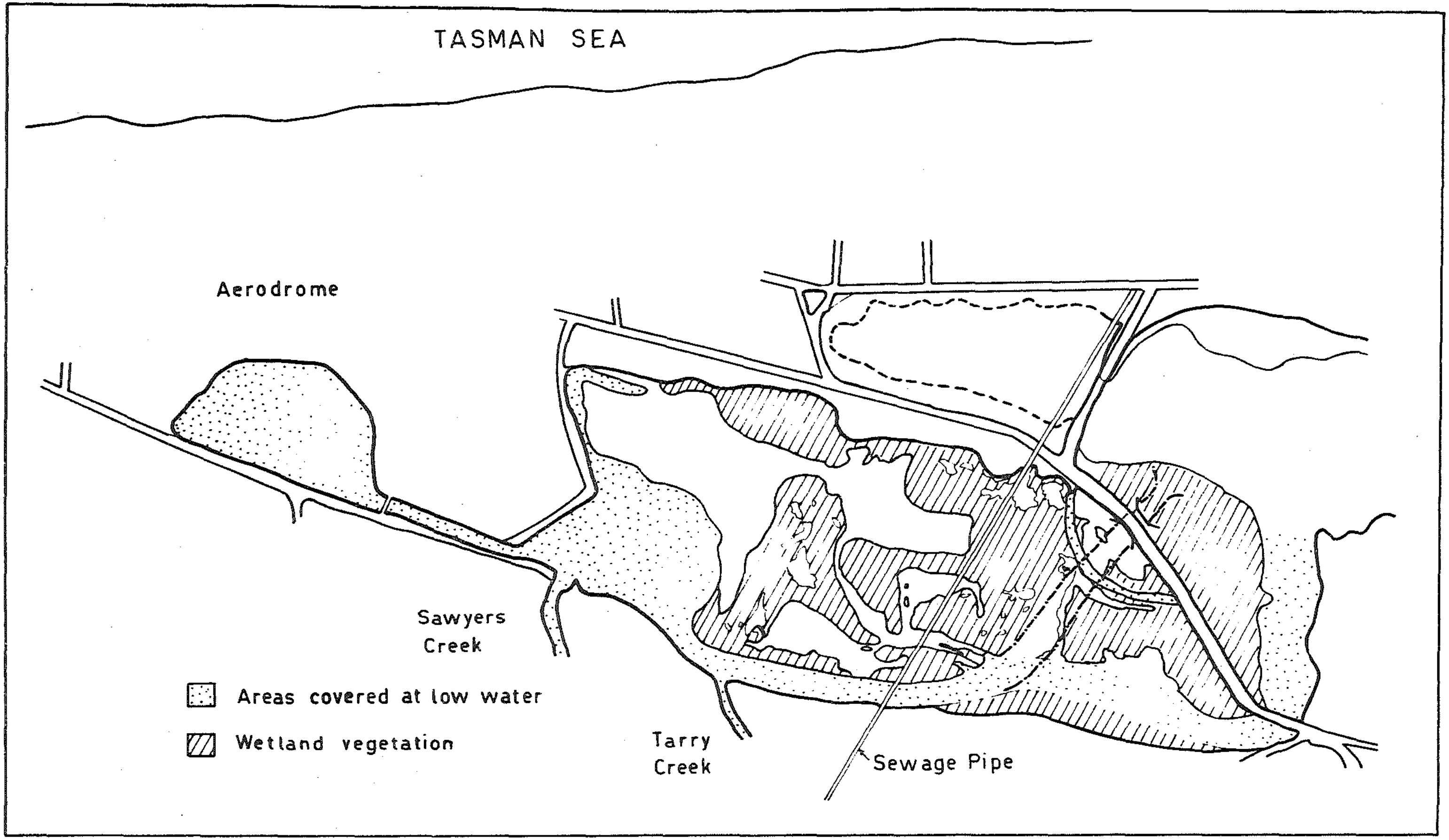

Fig. 2. The extent of Blaketown Lagoon in 1945. Traced from an aerial photograph. The dotted lines indicate the position of the present outlet.

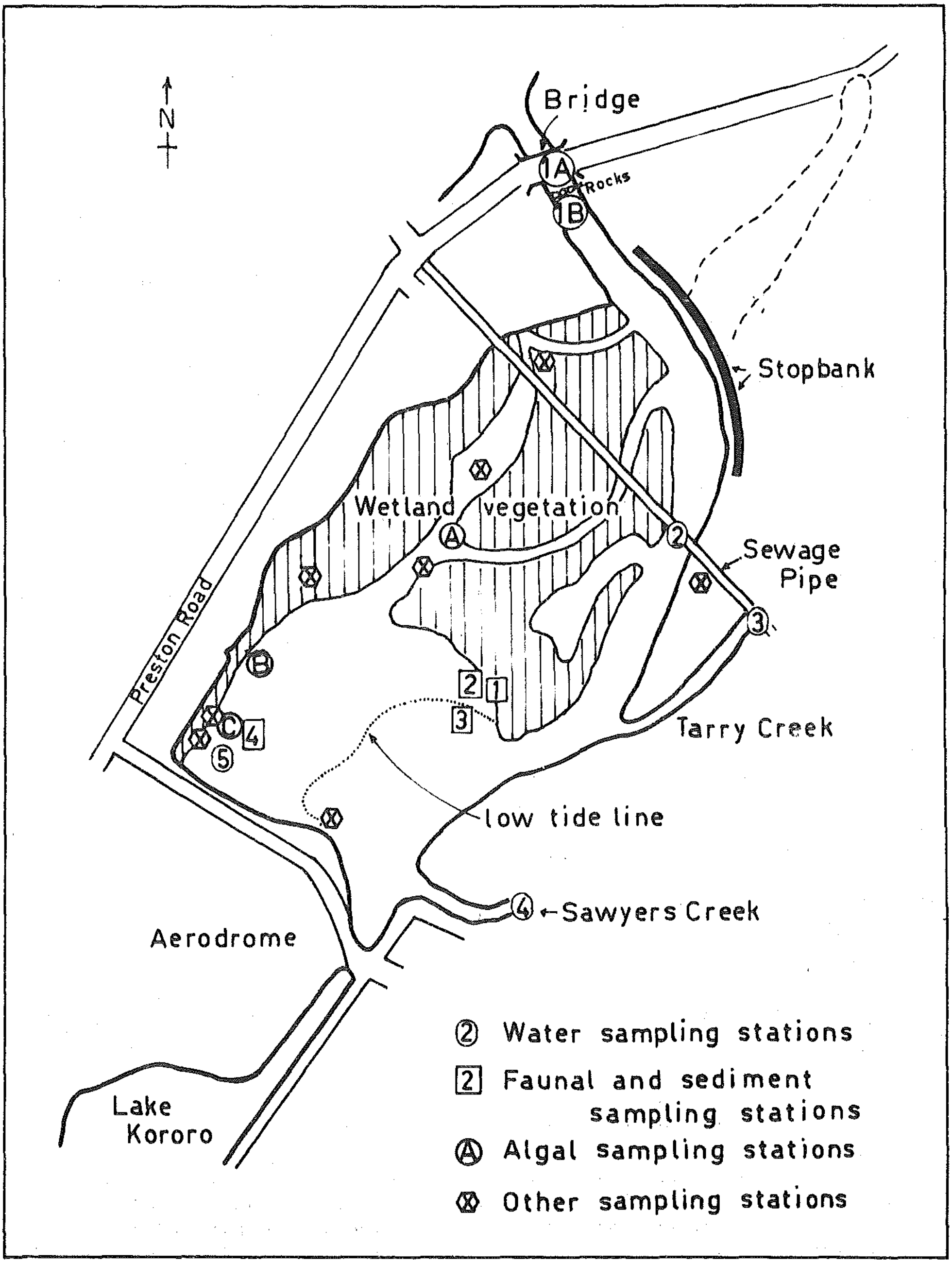

Fig. 3. Map of the Blaketown Lagoon showing the present extent of the vegetation and the sites of sampling stations.

vegetation. The remainder of the lagoon below Mean High Water Mark is vested in the Marine Division of the Transport Department. At Mean Low Water, more than two-thirds of the lagoon is uncovered.

VEGETATION

The greater part of the northern (seaward) half of the lagoon is covered with wetland vegetation (Fig. 3). From Fig. 2 it can be seen that, while in general, the outline of these areas is approximately the same as in 1945, they have extended in size across open areas of sand bank that were present then. These wetlands are also much denser without the open patches that were evident within the stands in earlier years.

Floristically, the vegetation is similar to that found in comparable estuarine wetlands in other parts of the South Island. On the West Coast, however, good representative stands of such a vegetation type are comparatively rare. The original vegetation occurs in a series of bands. On the seaward side there is a band of rushes and sedges, the principal species of which are the strong cylindrical sea rush *Juncus maritimus*, and the jointed rush *Leptocarpus similis*. The latter is particularly luxuriant in the lagoon. Locally dominant sedges include *Scirpus cernuus* and *Scirpus caldwellii* and probably other species. Filamentous algae, especially *Dictyota* sp., grow on the plants up to the limit of submergence at high water, and drift green algae lodge between the stems.

On the landward side the rushes and sedges merge into salt-tolerant introduced grass, *Agrostis stolonifera*, and the broad-leaved herb *Selliera radicans*. In places there are well-developed stands of the saltmarsh ribbonwood *Plagianthus divaricatus*. These species overlap in places with the rushes at their upper distribution, especially with *Leptocarpus*. There are many other associated species, such as the glasswort *Salicornia australis*, the shore pimpernel *Samolus repens*, the chenopod *Suaeda novaezelandiae* and plantains. These, however, have not been recorded in detail.

The area to the north of Sawyers Creek is designated a recreation reserve. It still retains some established remnants of native bush species, although gorse and blackberry are relatively common.

Of particular interest in this study were the plants growing on the mudflats below the *Scirpus*-*Juncus* zone. It was somewhat surprising to find a massive development of water weed *Ruppia*, as this does not normally grow in estuaries with sandy sediments or in areas of high salinity. Rather, it is characteristic of shallow, low salinity lagoons, such as Lake Ellesmere near Christchurch. *Ruppia* appears to be a recent immigrant into the lagoon, and the reasons for its presence there are discussed in detail later. In the early spring the upper mudflats were covered with 100 mm long emergent shoots of *Ruppia*, and the whole area had the appearance of a *Zostera* bed. The growth of this species by the late summer was considerable. At low tide the whole area was covered with a dense mat of *Ruppia* up to 150 mm thick in places, and large drifts of loose weed had accumulated along the strand line. It was the decay of this weed and the associated green algae that gave rise to offensive smells.

In the early spring, patches of green algae were common from mean high water to mid-tide level, especially along the western margin, and at the seaward margin of the *Leptocarpus-Juncus* zone. Two samples of these algae, and one of *Ruppia* were taken for biomass estimates at the points labelled A, B and C in Fig. 3. The wet and dry weights of these samples are given below.

TABLE 1. WET AND DRY WEIGHTS OF PLANT SPECIES FROM BLAKETOWN LAGOON.

Station	Plant species	Wet wt/m^2	Dry wt/m^2
A	*Cladophora*	3.68 kg	735 g
A	*Monostroma*	500 g	100 g
B	*Ruppia*	1.73 kg	385 g
C	*Vaucheria*	595 g	119 g
C	*Monostroma*	195 g	37 g

At station A there was in excess of 4 kg wet weight, a relatively high weight, for algal species. This compares, for example, with a maximum dry weight of 4 kg for the green algae *Ulva* and *Enteromorpha* recorded for the eutrophicated Avon-Heathcote Estuary during the spring growth (Knox and Kilner 1973).

A list of the important plant species recorded from the lagoon is given in Table 2.

TABLE 2. PLANTS RECORDED FROM THE BLAKETOWN LAGOON.

Species	Comments on distribution and abundance
Algae	
Enteromorpha prolifera	High tide
Enteromorpha nana	Mid tide
Vaucheria sp.	High tide
Cladophora crispata	Mid tide
Monostroma nitidium	High tide
Dictyota sp.	Amongst rushes and sedges
Oscillatoria sp.	Rare
Angiosperms	
Agrostis stolonifera	
Juncus maritimus	Abundant
Leptocarpus similis	Abundant
Plagianthus divaricatus	Common
Plantago sp.	
Ruppia megacarpa	Abundant
Salicornia australis	
Samolus repens	
Scirpus cernuus	
Scirpus caldwellii	
Selliera radicans	
Suaeda novazelandiae	

HYDROLOGY

The following account is based on an unpublished report by Mr A.W. Beck, Hydrologist, Westland Catchment Board, 4 September 1973. For this report a series of flow gaugings was taken of the incoming and outgoing tides at Preston Road Bridge. Based on these flow measurements, the following daily sequence of flow has been established (Fig. 4).

Outflow from the lagoon continues for three hours after low water in the Grey River estuary. This is due to the difference in water levels above and below the weir on the upstream side of Preston Road Bridge.

From the time the weir is covered by the incoming tide, the rate of flow into the lagoon increases from zero to a maximum of approximately 1000 cusecs on a spring tide and 800 cusecs on a neap tide. The maximum inflow occurs about one hour before high tide. Then, there is a fairly rapid slackening off of the rate of flow until zero flow occurs just after high tide.

After high tide, the rate of outflow increases rapidly to a maximum of about 750 cusecs on a spring tide. This rate is maintained for about one hour after high tide, then there is a steady fall in the rate of flow until zero flow occurs about eight hours later, when the tidal cycle recommences.

A gauging taken 15 minutes before the weir was submerged by the incoming tide gave an outflow of 16 cusecs. The flow in Sawyers Creek above the lagoon area at that time was eight cusecs. Taking into account the storage of flow from Sawyers Creek and other tributaries to the lagoon during an inflow period, it appears that most of the inflow runs out of the lagoon during the tidal cycle.

SALINITY

In February 1974, a series of investigations were carried out in order to determine the effect of the weir on the salinity regime within the lagoon. Salinity was measured with a portable Silver Springs Salinometer, and Table 3 compares salinity profiles at Preston Road Bridge with those taken at the end of the wharf on the Grey River estuary commencing 34 minutes after low tide. At that time it can clearly be seen that low salinity river water overlies the salt wedge penetrating up the estuary from the sea. As the tide rises, the salinity of this salt wedge increases and the salinities towards the surface increase. At the commencement (LT + 34 min.) the bottom salinity at Preston Road Bridge is 6.00‰ compared with a bottom salinity of 31.00‰ at the wharf. It was not until 4 hours 40 minutes after low tide that bottom water of high salinity (22.20‰) was recorded at the bridge. At that time the surface salinity at the bridge was only 3.80‰.

Table 4 and Fig. 5 compare the salinity profiles at the Preston Road Bridge with those at the weir upstream from the bridge. A number of points emerge from an examination of the data.

1. Surface salinities at the bridge are low, varying from 3.80‰ to 10.5‰ with the higher salinities occurring only during the latter thirty minutes of the inflow into the lagoon.

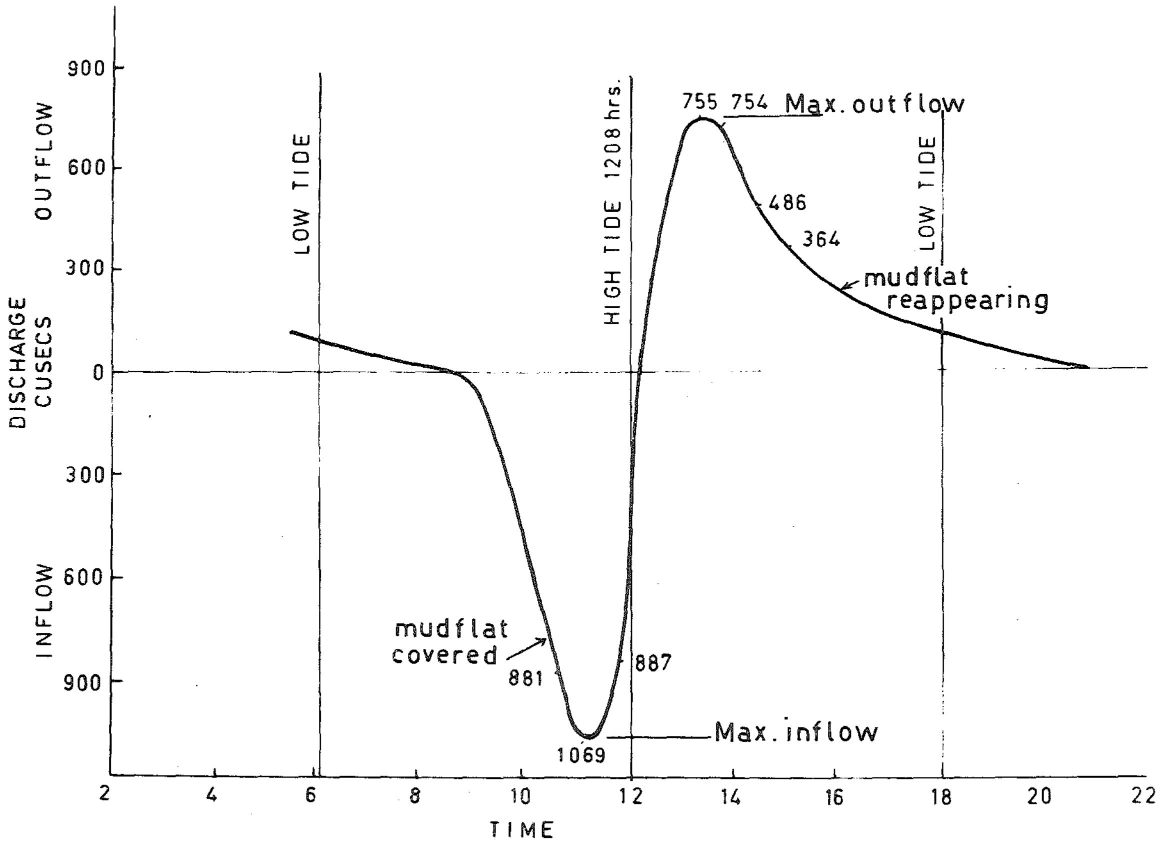

Fig. 4. Discharge hydrograph at Preston Road Bridge on 2 July 1973. (From Beck, 1973.)

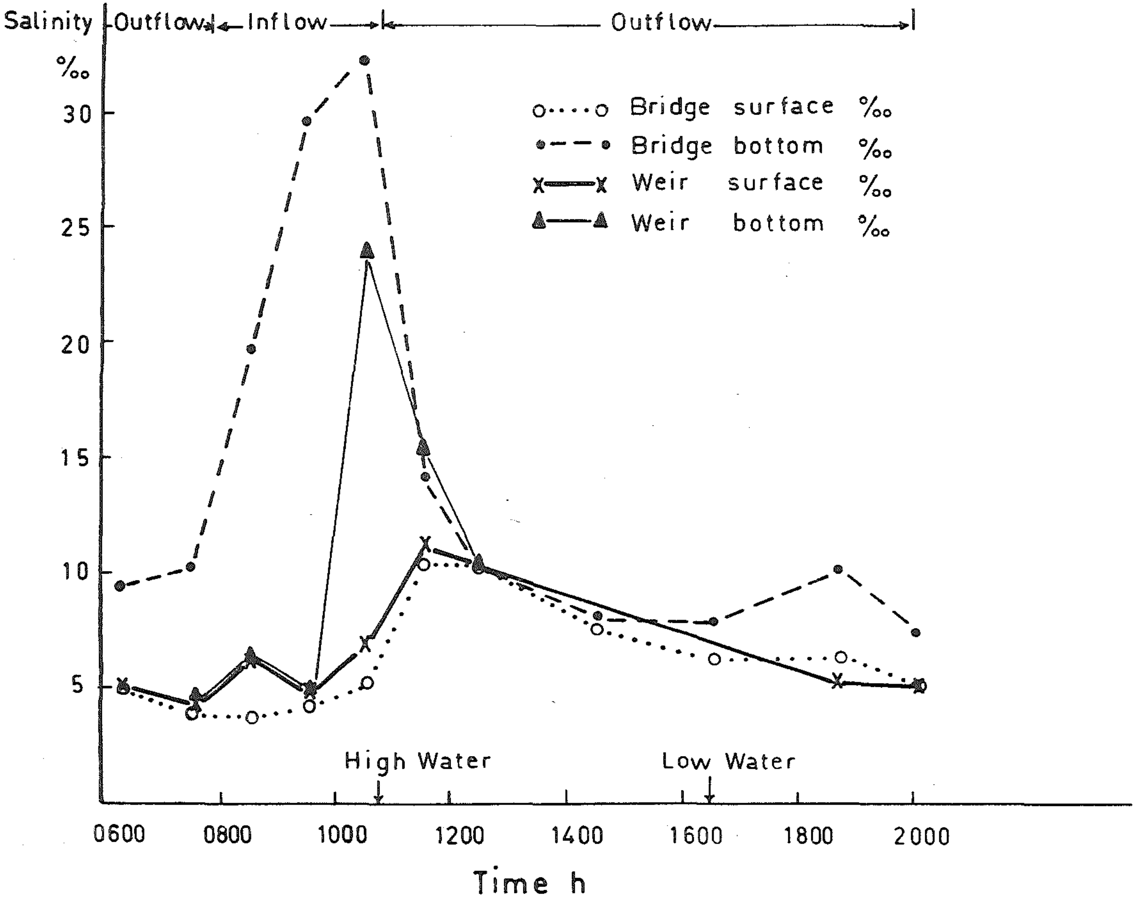

Fig. 5. Salinity profiles over a tidal cycle at Stations 1A and 1B, 21 February 1974.

TABLE 3. COMPARISON OF SALINITY AT PRESTON ROAD BRIDGE AND THE END OF THE WHARF ON THE RIVER, 20 FEBRUARY 1974.

Time	Approximate state of tide cycle	Salinity Bridge (Station 1A)	Time	Salinity End wharf
16.00	LT + 34 min.	S 4.00 B 6.00	16.30	S 1.00 -1m 8.00 -2m 25.00 -3m 31.00
18.00	LT + 2h 40min.	S 3.80 B 9.00	18.30	S 1.00 -1m 1.25 -2m 4.25 -3m 18.75 B 32.00
19.15	LT + 3h 40min.	S 3.80 B 10.00	19.30	S 1.5 -0.5m 2.7 -1m 15.5 -2m 31.0 -3m 31.0 B 31.5
20.30	LT + 4h 40min.	S 3.80 B 22.20		

S = Surface sample; B = Bottom sample; -Xm = Minus X metres depth;
LT = Low tide.

2. Bottom salinities at the bridge reach a maximum of 32.50‰ at high water.
3. Surface salinities at the weir are generally low, ranging from 3.80‰ to 5.20‰ over the outflow periods, and only exceed these values (with a maximum of 11.20‰) during the latter part of the inflow and the early part of the outflow. During this latter period the water running out will largely be water that has entered the main channel during the late part of the inflow.
4. The effect of the weir has been that over the first two hours of inflow it is only the incoming surface water of low salinity (4.50‰ to 6.90‰) that enters the lagoon over the weir.
5. It is only over the last hour of inflow that water of higher salinity (up to 15.20‰) is found at the bottom of the water mass flowing over the weir. At this time the surface salinity of water passing over the weir rises due to turbulent mixing.
6. The low salinity water entering the lagoon during the first two thirds of the inflow is diluted upstream from the inflows from Sawyers and Tarry Creeks. Thus salinities within the lagoon, especially in the upper parts, never reach high levels. Spot samplings in this upper region at various states of inflow and outflow did not exceed 5.00‰ and generally ranged between 3.50‰ and 4.50‰ .

TABLE 4. RESULTS OF OBSERVATIONS AT PRESTON ROAD BRIDGE OVER A COMPLETE TIDAL CYCLE, 21 FEBRUARY 1974. Conditions: Slight drizzle, Easterly wind 5-15 knots, 8/8 cloud, water moderately turbid.

	Station:	1B	1A	1B	1A	1B	1A			1B		
Tide	Time	Salinity above weir ‰	Salinity at bridge, ‰	Temp. above weir °C	Temp. at bridge °C	O_2 above weir mg/l	O_2 at bridge mg/l	Reactive PO_4	Total PO_4	Ammonia NH_3	Nitrate NO_3	Kjel N
Water flowing out	06.15	5.0	S 5.0 B 9.2	18.5	19.6	NT	10.3	Low	Low	Low	0.33	-
	07.30	4.0	S 3.8 -1m 5.0 B 10.0	18.0	18.3	9.8	10.3	Low	Low	Low	0.48	0.04
	08.25	6.2	S 3.8 -1m 10.0 B 19.5	18.2	18.5	NT	9.8	Low	Low	Low	0.27	Low
Water flowing in	09.30	8.5	S 4.2 -1m 12.5 -2m 29.5 B 29.5	19.0	19.2	NT	9.6	0.02	Low	Slight	0.38	Low
	10.30	S 6.9 B 24.0	S 5.2 -1m 20.2 -2m 31.0 B 32.5	17.8	18.9	NT	9.6	0.02	Low	Low	0.42	Low
	11.30	S 11.2 B 15.2	S 10.5 -1m 12.0 -2m 12.5 -3m 14.0	NT	19.0	NT	9.2	0.03	Low	Low	0.42	Low
Water flowing out	12.30	NT	S 10.2 B 10.2	NT	19.5	NT	NT	Low	Low	Slight	0.47	Low
	14.30	NT	S 7.5 B 7.9	NT	20.0	NT	9.6	0.02	Low	Slight	0.38	Low
	16.30	NT	S 6.2 B 7.8	NT	20.6	NT	9.6	Low	Low	Slight	0.38	Low
	18.30	S 5.2	S 6.2 B 10.0	NT	20.0	20.0	9.4	Low	Low	Low	0.44	Low
Water flowing in	20.00	NT	S 5.0 -1m 6.0 -2m 7.5 B 7.4	NT	18.5	NT	NT	Low	Low	Low	0.60	Low

S = Surface sample; -Xm = Minus X metres; B = Bottom sample; NT = Sample not taken. Nutrient values in terms of P or N g/m^3.

7. These salinities within the lagoon are thus very much lower than those that must have occurred before the new outlet was constructed and the weir installed. Salinities greater than 20.00‰ could easily have occurred especially from mid-tide levels down.

NUTRIENTS

On 2 November 1973 water samples were taken at high and low water at the five stations shown in Fig. 3, i.e. at:

1. Preston Road Bridge (1A)
2. From where the sewage pipe crosses the main channel (2)
3. From Tarry Creek (3)
4. From Sawyers Creek (4)
5. A station on the mudflat at the upper end of the estuary (5).

The analyses of these samples for nutrient content are given in Table 5, and details of analytical methods used are given in Knox and Kilner (1973).

TABLE 5. ANALYSIS OF WATER SAMPLES FROM BLAKETOWN LAGOON. (Nutrient values expressed as g/m^3.)

Station	Salinity ‰	Reactive PO_4	Total PO_4	Nitrate NO_3	Ammonia NH_3	Kjel N
Low tide						
1A	3.9	0.015	0.16	0.21	0.17	0.07
2	4.1	0.050	0.08	0.13	0.03	0.05
3	-	-	-	0.56	0.28	0.39
4	4.2	0.090	0.27	0.30	0.37	0.39
5	5.2	0.025	0.047	Low	0.005*	0.05
High tide						
1A	6.2	Low	0.050	0.12	0.007*	0.035
2	4.2	0.010	0.062	0.13	0.007*	0.005
3	3.9	0.030	0.210	0.15	0.55	0.12
4	4.6	0.210	0.590	0.27	0.065	0.15
5	5.2	0.030	0.130	0.14	0.005*	0.05

* These values are too low to be reliable but indicate very low levels.

Both reactive and total phosphorus levels generally fall within ranges that can be considered stimulating to plant growth. Early work by Ketchum (1939) and Goldberg *et al.* (1951) indicated that phosphate-P concentrations above 0.008 g/m^3 - 0.016 g/m^3 were no longer limiting to algal growth. Only at the lower stations (1A and 2) were levels below these limiting values found. At all low tide stations, and high tide stations 3, 4, and 5, the levels ranged from 0.015 g/m^3 - 0.210 g/m^3. Total phosphorus levels at high tide in both Tarry Creek (0.210 g/m^3) and Sawyers Creek (0.59 g/m^3) can be considered high. The relatively high levels at station 4 for the low tide samples (0.90 g/m^3 for reactive phosphorus and 0.27 g/m^3 for total phosphorus) are probably due to organic effluent that enters Sawyers Creek as it flows through urban Greymouth. These results differ from those obtained for example, from the Avon-Heathcote Estuary (Knox and Kilner 1973: 83) where, at a mid-estuary station, reactive phosphorus values ranged from 0.002 to 0.760 with a mean value of 0.150.

Ammoniacal N levels at stations 1A and 2 at high tide were low (0.007 g/m^3), similar to values recorded at high water at the mouth of the Avon-Heathcote Estuary (0.005 g/m^3)(Knox and Kilner 1973). Higher ammoniacal nitrogen levels (0.065 g/m^3 - 0.55 g/m^3) are recorded both for Sawyers Creek (station 4) and Tarry Creek. These compare with values ranging from 0.005 g/m^3 - 1.62 g/m^3, with a mean of 0.551 g/m^3, recorded for the entry of the Avon River into the Avon-Heathcote Estuary (Knox and Kilner 1973).

Within the lagoon proper (stations 2 and 5), the nitrate-N values ranged from 0.12 g/m^3 - 0.21 g/m^3. This compared with values of 0.01 g/m^3 - 0.51 g/m^3 (with a mean value of 0.204 g/m^3) recorded for the middle region of the Avon-Heathcote Estuary. From Table 4 it can be noted that the nitrate-N values in the late summer at the weir (station 1B) ranged from 0.33 g/m^3 - 0.60 g/m^3. These approach the maximum values recorded for the Avon-Heathcote Estuary, apart from stations at the point of discharge from the Bromley Oxidation Ponds where levels up to 1.20 g/m^3 were recorded.

In Table 6 the nutrient levels recorded in the two creeks are compared with the representative nutrient content of the Avon and Heathcote Rivers where they enter the Avon-Heathcote Estuary. In general it can be seen that the recorded levels are of a similar order of magnitude.

TABLE 6. COMPARISON OF SAWYERS AND TARRY CREEKS WITH THE AVON-HEATHCOTE RIVERS. (Nutrient values expressed as g/m^3.)

	Avon	Heathcote	Sawyers	Tarry
Reactive P	0.05	0.04	0.05	0.03
Total P	0.25	0.39	0.59	0.21
Ammoniacal N	0.21	1.40	0.37	0.55
Nitrate N	0.50	0.80	0.30	0.56

Nutrient levels similar to those recorded for the Blaketown Lagoon, for example, those of the Avon-Heathcote Estuary, have given rise to eutrophic conditions in estuaries with dense growths of green algae, especially of the genera *Ulva* and *Enteromorpha* (Jaworski *et al.* 1972, Perkins and Abbott 1972, Knox and Kilner 1973). Recent experiments on the relationship of algal growth to nutrients (Ryther and Dunstan 1972, Waite and Mitchell 1972, Waite *et al.*1972, Steffensen *in* Knox and Kilner 1973) indicate that both nitrogen and phosphorus in combination are important in stimulating plant growth. For example, Waite *et al.* (1972) found that when ammoniacal-N and phosphate-P were increased by a factor of 10 from 0.05 g/m^3 N and P to 0.5 g/m^3 N and P, the yield of *Ulva* increased by a factor of 50.

Knox and Kilner (1973) have discussed nutrient criteria needed to limit attached algal growths in estuaries. Following Pritchard (1969) and Jaworski *et al.* (1972), they suggested that mean total phosphorus levels should be maintained at mean values of about 0.04 g/m^3, and mean total nitrogen levels of about 0.40 g/m^3. Total phosphorus levels, in particular, are far in excess of these values in Blaketown Lagoon.

SEDIMENTS

Sediment samples using a 100^2 mm corer were taken from stations 1, 2 and 3 in the central mudflat area. The results of the analyses on these samples are given in Table 7.

TABLE 7. SEDIMENT ANALYSES FROM BLAKETOWN LAGOON.

Sediment particle size	Station		
	1	2	3
% gravel	0.3	0	0
% coarse sand	1.8	0.7	1.0
% fine sand	1.0	5.3	7.0
% silt	76.0	75.0	76.0
% clay	21.0	19.0	16.0
% silt and clay (total)	97.0	94.0	92.0
% organic matter	7.21	6.17	5.54

All of the sediment samples had a silt-clay fraction over 90%, and resemble those generally found in estuaries that have been subjected to organic pollution. They are similar to those found, for example, in the Avon-Heathcote Estuary adjacent to the outflow from the Bromley Oxidation Ponds, and along Humphries Drive where large masses of unattached algae accumulate and rot (Knox and Kilner 1973). Sediments with high silt-clay fractions also tend to have a high organic content, and this is true for the sediments from the Blaketown Lagoon.

The 1/20 m^3 samples were washed through a series of sieves (up to 2 mm) for faunal analysis. The plant litter present in the sediment was kept for dry weight determinations, and the results of these are given in Table 8.

TABLE 8. DRY WEIGHT OF PLANT LITTER FROM SEDIMENT, BLAKETOWN LAGOON.

Station	Dry weight	
	g/ 1/20 m^3	g/m^2
1	845	17 900
2	75	1 500
3	20	400
4	40	800

Station 1 was adjacent the *Leptocarpus-Juncus* band, and the very high weight of plant material was due to the presence of root material of these species.

In spite of their high organic content and fine character, the sediments did not show the typically reduced condition with a black layer smelling strongly of hydrogen sulphide close to the surface. This is probably due to the fact that the input of organic material has been a relatively recent occurrence.

Towards the lower end of the lagoon at the X station between A and the sewage pipe (Fig. 3), the sediments still retained something of their original character, and were quite firm and sandy. These sediments are similar to those in Erua Moana, and give an indication of the original condition of the lagoon.

BOTTOM FAUNA

Table 9 gives the results of the analysis of the four faunal sampling stations. Replicate samples were taken with a 1/20 m^2 box sampler.

Station 1 had the largest quantity of organic matter and the highest percentage of silt-clay of all the stations, and the fauna was most diverse and numerous here. Small snails (*Potamopyrgus* spp.), and amphipods (*Melita awa* and *Orchestia* sp.) and polychaetes were numerous, and crabs were present only at this station.

The other three samples had fewer animals. *Potamopyrgus* spp., the polychaete *Scolecolepides* and amphipods decreased in numbers towards the head of the lagoon. Conversely, chironomids became more numerous, and pupae were found in numbers only at station 4.

Galaxids (Galaxiidae), probably juvenile whitebait, were found among the strands of *Ruppia* at stations 2 and 3. The occurrence of these fish indicates that the extent of organic pollution has not reached levels inimical to fish life, as juvenile fish are much more sensitive to pollution than adults. The uniformly high oxygen concentrations within the lagoon (Table 4) are suitable for fish survival.

The minimum sieve size was too large to retain the numbers of nematodes and oligochaetes present. If these were adequately sampled it is probable that numbers would be many thousands per square metre.

Two species of chironomids, *Chironomus zealandicus* and *Anatopynia* sp. were found. The latter species is predaceous, and may feed on the young stages of *C. zealandicus*.

Three species of the gastropod snail *Potamopyrgus* occurred: *P. estuarinus, P. antipodarum* and *P. pupoides*. Proportions of the various species from station 2 retained by the different sized sieves are shown in Table 10. This shows that the large individuals were mainly *P. estuarinus,* the intermediate sizes *P. antipodarum,* and the small ones *P. pupoides*.

Towards the lower part of the lagoon where the sediments were sandier and firmer, the mudflat snail *Amphibola crenata* and the burrowing crab *Helice crassa* were reasonably common. Both these species are excluded from the very fine sediments.

TABLE 9. ANALYSIS OF BENTHIC FAUNAL SAMPLING STATIONS. Figures are numbers of individuals per 1/20 m^2.

Animals	Station 1	2	3	4
Nematoda				
Unidentified nematodes	+	+	+	+
Gastropoda				
Amphibola crenata	-	-	-	1
Potamopyrgus spp.	2728	2114	1556	1296
Polychaeta				
Scolecolepides benhami	57	27	75	10
Oligochaeta				
Unidentified oligochaete	+	+	+	+
Crustacea				
Amphipoda				
Melita awa	195	8	16	
Orchestia sp.	-	-	-	1
Isopoda				
Unidentified isopod	3	3	-	-
Decapoda				
Helice crassa	7	-	-	-
Insecta				
Chironomid spp.				
Larvae	11	7	18	274
Pupae	-	-	2	33
Pisces				
Galaxiid juveniles	-	7	5	-
Eel elvers	1	-	-	-
Total numbers counted	3003	2168	1675	1414

+ = present; - = absent.

TABLE 10. PERCENTAGES OF DIFFERENT *POTAMOPYRGUS* SPECIES RETAINED IN DIFFERENT SIZED SIEVES.

Species	Sieve mesh size, μm 2 000	1 400	1 000	600
P. estuarinus	85%	5%	0%	0%
P. antipodarum	15%	95%	100%	95%
P. pupoides	0%	0%	0%	5%

In the Avon-Heathcote Estuary, *Amphibola* was not found on sediments with silt-clay fractions exceeding 85% (Voller 1973) and the crab *Helice crassa* has a similar upper limit.

The striking characteristic of the Blaketown Lagoon fauna is that it is composed exclusively of species that are tolerant of very low salinities. Voller (1973) and Estcourt (1962, 1967) found that the polychaete *Scolecolepides benhami*, common in Blaketown Lagoon, extended almost into freshwater in the Avon-Heathcote Estuary. Voller gives a minimum mean interstitial salinity or bottom water salinity of 0.50‰ for this species. Oligochaetes and snails (*Potamopyrgus* spp.) are characteristic of fresh or slightly brackish water. For example, Voller (1973) found that *P. estuarinus* had a minimum mean interstitial or bottom water salinity of 0.8‰, and in the Avon-Heathcote Estuary this species penetrates only a short distance into the Estuary proper (from the Avon River only as far as the Pleasant Point jetty). Conversely, *P. antipodarum* is considered a freshwater species with a very low salinity tolerance.

Typical estuarine animals that could previously have occurred within the lagoon but are now no longer present due to the changed conditions are the polychaetes *Aglaophamus macrura*, *Aonides trifidus*, *Capitella capitata* and *Orbinia papillosa*, the bivalves *Chiona stutchburyi*, *Cyclomactra ovata* and *Macomona liliana*, and the gastropods *Micrelenchus huttoni* and *Zediloma subrostrata*. Most of these species occur in the sandier and more saline Erua Moana.

GENERAL CONCLUSIONS

1. The Blaketown Lagoon has undergone considerable biological changes from its original condition, due to human impact.
2. These impacts have resulted from:
    a. reclamation
    b. the closing of the old outlet and the construction of a new one
    c. the construction of a weir upstream from Preston Bridge in the new outlet channel
    d. the inflow of sewage and industrial effluents from Sawyers and Tarry Creeks
    e. the indiscriminate dumping of rubbish along the margins and in Tarry Creek.
3. The construction of the weir has had the following effects:
    a. it has altered the normal flow pattern of approximately six hours inflow and six hours outflow to one of approximately three hours inflow and nine hours outflow
    b. it has raised the water level in the lagoon at low tide by about 0.67 m (1.9 ft).
    c. it has altered the salinity regime within the lagoon from that of a normal estuary to one in which the salinities throughout the greater part of the tidal cycle do not exceed 5.0‰.
4. The input of nutrients (nitrogen and phosphorus in their various forms) into the lagoon has increased considerably. The increased nutrient levels arise from more or less

permanent overflows of domestic sewage into Sawyers Creek and the input of industrial effluent, especially from a gas works and a brewery into Tarry Creek.

5. In general, nutrient levels are similar to those recorded for the Avon-Heathcote Estuary, an estuary subject to nuisance growths of green algae.

6. Largely as a result of the input of organic material, increased plant growth, lessened current flow and the raising of the low tide level, the sandy character of the sediments has changed to predominantly muddy sediments with silt-clay fractions of over 90‰ and relatively high concentrations of organic matter.

7. The input of nutrients has caused an accelerated growth of the wetland vegetation and an increased growth of green algae. The lowered salinity has favoured algal species characteristic of waters of low salinity and has enabled the establishment of the water-weed *Ruppia* on the mudflats. This latter plant is characteristic of low salinity lagoons, such as Lake Ellesmere near Christchurch. It is the decay of massive growths of *Ruppia* and associated algae in the summer that is responsible for the "smell" problem.

8. The increased percentage of the silt-clay fraction, and the large amounts of organic matter and the lowered salinities have changed the benthic fauna from a true estuarine fauna to one characteristic of slightly brackish water. Estuarine bivalves such as cockles (*Chione stutchburyi*) and the wedge-shell (*Macamona lilliana*) are absent, and freshwater species, or ones tolerant of extremely low salinities, such as the polychaete *Scolecolepides benhami*, oligochaetes, gastropods of the genus *Potamopyrgus* and chironomid larvae are common.

9. The lagoon forms an important feeding and nesting area for a range of aquatic birds (J. Adams, pers. comm.).

10. Indiscriminate dumping of rubbish has added to the general untidiness of the lagoon and its surroundings.

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LITERATURE CITED

BECK, A.W. 1973. Sawyers Creek investigation at Blaketown Lagoon. Unpublished report to the Westland Catchment Board, Greymouth.

ESTCOURT, I.N. 1962. An ecological survey of the burrowing polychaetes of the Heathcote-Avon Estuary. Unpublished M.Sc. thesis, Department of Zoology, University of Canterbury, New Zealand. 128 pp.

ESTCOURT, I.N. 1967. Ecology of benthic polychaetes in the Heathcote Estuary, New Zealand. *New Zealand Journal of Marine and Freshwater Research 1*: 371-394.

GOLDBERG, E.D., WALKER, T.J. and WHISENAND, A. 1951. Phosphate utilization by diatoms. *Biological Bulletin 101*: 274-284.

JAWORSKI, N.A., LEAR, D.W. and VILLA, O. 1972. Nutrient management in the Potomac Estuary. *In*: Likens, G.E. (Ed.)., *Nutrients and eutrophication*, 246-273. *American Society of Oceanography Limnology, Special Symposium*, Vol. 1.

KETCHUM, B.H. (Ed.) 1972. *The waters edge: critical problems of the coastal zone*. MIT Press, Cambridge, Massachusetts. 393 pp.

KNOX, G.A. and KILNER, A.R. 1973. *The ecology of the Avon-Heathcote Estuary*. Report to the Christchurch Drainage Board by The Estuarine Research Unit, Department of Zoology, University of Canterbury, Christchurch. 358 pp.

PERKINS, E.J. and ABBOTT, O.J. 1972. Nutrient enrichment and sand flat fauna. *Marine Pollution Bulletin 3*: 70-72.

PRITCHARD, D.W. 1969. Dispersion and flushing of nutrients in estuaries. *Journal of the Hydraulics Division, American Society of Civil Engineers 95*: 115-124.

RYTHER, J.H. and DUNSTAN, M.W. 1972. Nitrogen, phosphorus and eutrophication of the coastal marine environment. *Science 1711*: 1008-1013.

VOLLER, R.W. 1973. Salinity, sediment, exposure and invertebrate macro-faunal distributions on the mudflats of the Avon-Heathcote Estuary, Christchurch, New Zealand. M.Sc. thesis, Department of Zoology, University of Canterbury, New Zealand. 62 pp.

WAITE, T.D. and MITCHELL, R. 1972. The effect of nutrient fertilization on the benthic alga *Ulva lactuca*. *Botanica marina 15*: 151-156.

WAITE, T.D., ASCE, A.M. and MITCHELL, R. 1972. Role of benthic plants in fertilized estuary. *Journal of Sanitary Engineering 98*: 763-770.